QoS in B-ISDN (ATM) networks

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Layered model
- Used for traffic characterization and QoS definition
  - Call level
  - Burst level
  - Cell level

Call level
- Long-term temporal dynamics
- The traffic occupies network resources for the full call duration
- Traffic characterization
  - Call attributes
  - Call model
- Quality of service

Burst level
- Medium-term temporal dynamics
- ON-OFF periods
  - Traffic characterization:
    - OFF periods stochastic duration
    - Burst length stochastic duration
    - Bit rate during ON periods (peak rate assumed)
- Quality of service undefined

Burst level
- Burstiness: $\beta = \frac{H+K}{H}$
- Activity coefficient: $\alpha = \frac{1}{\beta}$
- Average bit rate: $B_M = \alpha B_P$
- Bit rate variance: $\sigma^2_B = B_M(B_P - B_M)$
**Cell level**

- **Traffic characterization:**
  - Inter-arrival time distribution
  - Distribution of the number of cells generated in a measurement period T
  - Often less information is accepted (also for complexity reasons)
    - Inter-arrival expected value and variance
    - From the average inter-arrival time the average bit-rate can be computed
  - Quality of service:
    - reliability
    - Cell loss probability
    - Cell error probability
    - Cell mis-insertion probability (cells belonging to other VC erroneously inserted in the current VC)
    - Expected value, variance and maximum cell delay

**Standard**

- A traffic contract was defined
  - Traffic characterization
    - Accurate
    - Uniquely verifiable
    - Simple, to be useful for the computation of network resources that should be allocated to the connection
  - QoS guarantee
    - Parameters defined in the ITU-T I.356 recommendation

**Standard: traffic characterization**

- Identification of cell flows within a connection
- Definition of traffic intrinsic parameters
  - Traffic nominal characteristics in absence of interfering traffic
- Tolerance: accepted variations with respect to nominal characteristics
  - CDVT: Cell Delay Variation Tolerance
- Conformance definition
  - GCRA algorithm (Generic Cell Rate Algorithm)

**Standard:**

- Connection starting time
- Connection ending time
- 1/PCR (cell/s)
- MBS (number of cells)
- Connection duration
- SCR = number of cells / connection duration
** Relation between SCR and IBT **

Ideal arrival process at SCR, used as a reference

** GCRA: **

** Generic Cell Rate Algorithm **

- Standard algorithm for conformance verification (policing) and for traffic adaptation (shaping)
- **PARAMETERS:**
  - $T$ = nominal cell inter-arrival time
  - $\tau$ = tolerance or maximum accepted variation with respect to nominal spacing
- **VARIABLES:**
  - $T_a$ = real cell arrival time
  - $TAT$ = theoretical cell arrival time

** Conformance verification **

- Statistical multiplexing stages (switching nodes) modify the original traffic pattern due to unpredictable queuing delays
- Cell Delay Variation Tolerance (over SCR and/or PCR)
- CDVT
  - Maximum acceptable ahead time at an interface with respect to the expected arrival time
  - Similar to IBT, but to cope with multiplexing delays, not to allow some variability in the user flow
- If GCRA is checking the PCR
  - $T=1/PCR$
  - $\tau=CDVT_{PCR}$
- If GCRA is checking SCR
  - $T=1/SCR$
  - $\tau=IBT + CDVT_{SCR}$

** Quality of service: standard ITU-T I.356 **

- **CTD (Cell Transfer Delay)**
  - Average time between the transmission of the first bit and the reception of the last bit
- **2-pt CDV (Two point Cell Delay Variation)**
  - Variation of cell delivery time
  - Difference between the 10^{-8} inferior and superior quantile of CTD
- **CLR (Cell Loss Ratio)**
  - Cell loss probability
  - Ratio between lost cells and transmitted cells
  - $CLR_0 \leq CLR_{10^{-8}}$
- **CER (Cell Error Rate)**
  - Ratio between cells with detected errors and the total number of cells
- **CMR (Cell Misinsertion Rate)**
  - Ratio between erroneously received cells (cells belonging to other VCs) and the total number of received cells
- **SECBR (Severely Errored Cell Block Ratio)**
Quality of service classes

- Defined through some parameters:
  - CLR
  - CDV
- 4 QOS service classes standardized by ITU-T to satisfy 4 main types of user services:
  - Class 1: STRICT (CLR<0\(+1\))
  - Class 2: TOLERANT (CLR<0\(+1\))
  - Class 3: LIMITED (CLR<0\)
  - Class U: BEST EFFORT (does not admit negotiation of any parameter)

Transfer modes

- ITU-T: internationally recognized standardization body
- ATM forum: de-facto standardization body
- Transfer modes defined
  - By ITU-T as ATC (ATM Transfer Capability)
  - By ATM Forum as Service Class
- Transfer mode distinguished through definition of:
  - Cell flows to which guarantees are provided
  - Parameters to characterize flows
  - Conformance verification applied to flows
  - Adopted control functions

Transfer modes

- Do not define QoS requirements
  - Each transfer mode can be associated (almost) with any negotiable QoS
- Five main transfer modes:
  - CBR/DBR: Constant/Deterministic Bit Rate
  - VBR/SBR: Variable/Statistical Bit Rate
  - UBR: Unspecified Bit Rate
  - ABR: Available Bit Rate
  - ABT: ATM Block Transfer
- ABT ed ABR use RM cells to control flow cell emission rate

Transfer modes

- Define ATM layer services and the associated QoS
- To each service, a set of admissible QoS parameters values is defined
- Network operators may add other QoS parameter values beyond the standardized ones

Transfer modes: DBR

- Characterization:
  - PCR over aggregated flow (data+OAM+RM) or
  - PCR over data+OAM flow
  - Does not use the CLP bit
- Offers static bit rate equal to the negotiated PCR (possibly more than PCR)
- Use a single instance of GCRA
- Isochronous services or fixed bit rate services
- CAC over $B_p$ (or $B_{eq}$)
- Associated with service class 1

Transfer modes: SBR

- Characterization (3 flavor):
  - SBR1: PCR, SCR and MBS over aggregated flow
  - SBR2: PCR over all data cells (0+1), SCR (0), MBS (0). Tagging over non conformant cells not admitted
  - SBR3: like SBR2, but tagging of non conformant cells is admitted
- Offer a variable bit rate, normally ranging between PCR e SCR to satisfy source needs, not network needs
- Always two instances of GCRA are used
- Isochronous service or data services with variable bit rate
- CAC over $B_p$, $B_{eq}$, $B_{eq}$ or exploiting measurements
  - Allocated bandwidth must be guaranteed through a proper scheduling algorithm
- Typically, loss rate and delays are negotiated
QoS in B-ISDN Networks

Transfer modes: UBR

- Standardized only by ATM Forum
  - ITU-T: UBR can be obtained as DBR with U class of service
- Characterization:
  - PCR over aggregated flow
- No conformance definition
- No bit rate allocation, no QoS guarantees on delays and loss probabilities
- Switches exploit cell discarding techniques
  - To reduce segmentation negative effects
  - "Useless" traffic transported
  - Loss priority in buffers

UBR: cell discarding

- Selective Cell Discarding:
  - Drop cells belonging to a (higher layer) packet/message for which at least another cell was already dropped
  - Packet identification is easy for AAL5
  - Some "useless" traffic due to head of packets (already transmitted cells)
- Early Packet Discarding:
  - Discard full messages (entire set of cells) when the buffer occupancy exceeds a given threshold
  - Higher layer packets segmented in cells are either entirely transferred or dropped,
    - When the buffer occupancy exceeds the threshold, cells belonging to packets already partially transmitted are stored and later transmitted, cells belonging to new packets are dropped
    - Need to set up threshold value properly depending on (average?) packet size and buffer size

Other cell discarding mechanisms

- Use of the EFCI bit in the cell header PT field:
  - Used to indicate congestion to protocol layers higher than ATM
  - It is assumed that higher layer protocols react to congestion signals
- Cell discarding based on priority:
  - If buffer size occupancy becomes critical (e.g.: full buffer or buffer occupancy over threshold) low priority cells (CLP=1) are discarded
  - Divided in two categories:
    - Non protective
      - High priority may suffer losses due to low priority packets previously stored
    - Protective (full separation between high and low priority)
      - Need to control cell generation process

Transfer modes: ABR

- ABR (Available Bit Rate) offers an allocated bit rate between PCR and MCR depending on network resources availability; goals
  - Full bit rate utilization
  - Fair resource partitioning
- The network explicitly signals to sources the transmission bit rate
- It provide small CLR (ideally zero CLR) if source adapt their rate to network indication

Transfer modes: ABR

- Characterization:
  - PCR over aggregate flow (data+OAM+RM)
  - MCR (Minimum Cell Rate) over aggregated flow (data+OAM+RM)
- Conformance definition based on GCRA with parameter T adapted to network signals
- Source behavior completely specified in standards
- Node algorithms, as usual, not standardized

Transfer modes: ABR

- Uses in-band RM cells (forward e backward) to obtain a continuous control of source emission bit rate (cooperating sources)
ABR: source behavior

• An ABR source
  – Starts transmission at a negotiated rate (ICR)
  – Periodically inserts RM forward cells in cell flow
  – When it receives an RM backward cell it adapts the transmission rate to the minimum value contained in the cell
  – If no RM backward cells are received, the source slows down until it stops
  – If the source is silent more than a given period, it starts transmitting at the negotiated rate

ABR: node behavior

• Three possibility to control source emission rate:
  – EFCI (Explicit Forward Congestion Indication):
    • Equivalent to the congestion notification used in frame relay
    • 1 control bit to signal congestion
    • It is the simplest but less efficient mechanism
    • Destination translate EFCI bits into a CI bit in backward RM cells
  – RRM (Relative Rate Marking): nodes send on backward RM cell a ternary information through two bits (CI,NI) setting (increase rate, keep rate, decrease rate)
  – ER (Explicit Rate): nodes send on backward RM cells the rate at which a source can send cells
• Nodes overwrite info in RM cells only if constraining more source behavior

ABR: node behavior

• When adopting EFCI and RRM schemes, nodes normally control congestion by monitoring buffer occupancy
• Threshold mechanism:
  – Single FIFO, occupancy based (positional)
    • Hysteresis
  – One FIFO per VC
  – Derivative
  – Integrative
• ER: nodes control congestion measuring traffic load (background, ABR) and the number of active ABR connections

ABR: RM cell main fields

• Protocol type (ABR, ABT)
• Direction (Forward, Backward)
• NI (No-Increase), CI (Congestion Indication) bits
• ECR: Explicit Cell Rate
• CCR: Current Cell Rate
• MCR: Minimum Cell Rate
• ...

ABR: some parameters

• Parameters negotiated when opening the VC
  – PCR: Peak Cell Rate
  – MCR: Minimum Cell Rate
  – ICR: Initial Cell Rate
  – Source start sending at ICR. Ranges between PCR and MCR
  – RIF: Rate Increase Factor
    – Negative power of 2, referring to PCR
  – RDF: Rate Decrease Factor
    – Negative power of 2, referring to CCR
  – TBE: Transient Buffer Exposure
    – Amount of data that can be transmitted without receiving backward RM cells

ABR: RRM

• Two control bits:
  – CI (Congestion Indication)
  – NI (Not Increase)

<table>
<thead>
<tr>
<th>CI</th>
<th>NI</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Increase</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Keep</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Decrease</td>
</tr>
</tbody>
</table>

With respect to CCR (Current Cell Ratio)

• Two parameters are negotiated: RDF e RIF (Rate Decrease/Increase Factor)
• To increase rate: CCR=CCR+PCR·RIF
• To decrease rate: CCR=CCR·(1-RDF)
• Nodes cannot flip to 0 a bit set to 1 by other nodes!
**ABR: example of an RRM algorithm**

- Not standardized
- Measure $Q_i$, queue length at $i$, and $D(Q_i) = Q_i - Q_{i-1}$
- Define two thresholds: $L$, $H$, with $L < H$
  - Positional control
    - $Q_i < L$  $\Rightarrow$ $NI=0$  $CI=0$
    - $L < Q_i < H$  $\Rightarrow$ $NI=1$  $CI=0$
    - $H < Q_i$  $\Rightarrow$ $CI=1$
  - Positional - Derivative control
    - $\forall Q_i$  $D(Q_i) < \beta$  $\Rightarrow$ $NI=0$  $CI=0$
    - $\exists Q_i$  $\beta < D(Q_i)$  $\Rightarrow$ $CI=1$
    - $Q_i < L$  $\Rightarrow$ $\beta < D(Q_i) < 0$  $NI=0$  $CI=0$
    - $Q_i < L$  $0 < D(Q_i) < \beta$  $NI=0$  $CI=0$
    - $L < Q_i < H$  $\Rightarrow$ $\beta < D(Q_i)$  $NI=1$  $CI=0$
    - $H < Q_i$  $\Rightarrow$ $0 < D(Q_i) < \beta$  $NI=0$  $CI=0$

**ABR: ER**

- Example of an algorithm (not standardized): ERICA
  - DATA:
    - $C$: link bit rate
    - Available bit rate
      - Bit rate available to ABR connections, i.e., subtract from link capacity the bit rate devoted to CBR and VBR VCs
    - Target bit rate: $R_T = 0.98 \cdot C$
      - To avoid oscillations
  - OUTPUT:
    - Fair share bit rate: $B_{FSi}$

**ABR: ERICA**

- Once the target bit rate is set, e.g. $R_T = 0.95 \cdot C$
- Estimate
  - The number of active ABR connections ($N_{ABR}$)
  - Background traffic ($L_B$)
  - ABR connection current load ($L_{ABR}$)
- Compute:
  - Available bit rate for $i$: $B_{AVRi}=R_T-L_B$
  - $B_{AVRi}$  $\leq$ $N_{AVR}$
  - $L_B+L_{AVR}$  $\leq L_{ABR}$
  - $B_{FSi}=\max(B_{FSi}, B_{VCi})$
- The maximum allows to target a max-min fair allocation
- $B_{FSi}$ is written in the ER field only if smaller than the current value

**Transfer modes:**

**ABT (ATM Block Transfer)**

- Standardized only by ITU-T
- Defines a block of cells as a group of cells “enclosed” by two RM cells (or preceded by one RM cell)

**ABT**

- Two flavours:
  - IT (Immediate Transmission):
    - Send a block of cells at a constant bit rate, equal to BCR
    - Each node either discards or accepts the full block
      - Rather inefficient when crossing several nodes
    - Exploits part of the available bandwidth for short periods
    - Acceptance can be done looking at bit rate only, at buffer only, or at both
  - DT (Delayed Transmission):
    - Can re-negotiate block transfer rate, but need to wait for a positive answer from the network
    - Continuous negotiation, without exploiting signalling resources
Exercise

• Discuss a possible architecture to support ATM transfer modes
  – Queuing structure
  – Schedulers
• Start by considering each transfer mode separately